

Chapter 6

Summary

This monograph has introduced and discussed a number of different bandwidth-efficient modulation schemes, in each case emphasizing the trade-off between their amount of envelope (or instantaneous amplitude) fluctuation and their bandwidth efficiency. While not specifically focused upon, the trade-off between power and bandwidth efficiency is also of importance. One means of illustrating this trade-off is via a plot of throughput efficiency (or its reciprocal) versus E_b/N_0 required to achieve a given error probability. In the next section, we offer such plots, obtained from a combination of simulation and analysis for many of the modulations (with and without error correction coding) discussed earlier. The measure of spectral containment used to arrive at the throughput is the 99 percent in-band power, which is equivalent to the -20 -dB crossing on a fractional out-of-band power chart. Both unfiltered and filtered cases will be considered, the latter being of interest when the need arises to further restrict the transmitted RF bandwidth beyond that inherently achieved by the generic modulation technique.

6.1 Throughput Performance Comparisons

A 3-phase study [1–3] conducted by the CCSDS in response to an action item from the SFCG identified 10 modulations commonly used or planned by space agencies for bandwidth-efficient applications. The 10 modulations so identified were: PCM/PM/NRZ, PCM/PM/Biphase, QPSK, MSK, 8-PSK, BPSK/NRZ, BPSK/Biphase, OQPSK, GMSK, and FQPSK-B. The objective of the study was to compare these modulation methods, using a combination of simulation and analysis in terms of the E_b/N_0 required to maintain the data BEP at a given constant level. For the cases where very low BEPs were required, a concatenated coding scheme (a combination of a rate $1/2$, constraint length 7 inner

convolutional code with a Reed-Solomon 223,255 outer block code) was used. Some results for turbo-coded and trellis-coded modulations were also obtained. Nonideal data and system parameters (e.g., data imbalance) were included in the simulation models to make the results appear as realistic as possible. Where filtering was employed, a three-pole Butterworth baseband filter was used. Finally, to simulate the hard-limiting (nonlinear) effect of an SSPA, the simulation model also used the characteristics of the European Space Agency's SSPA operating in full saturation.

Figures 6-1 and 6-2 are illustrations of the reciprocal of the throughput (the ratio of two-sided 99 percent bandwidth for RF transmission to the data rate) versus the E_b/N_0 required to maintain data BEPs of 10^{-3} and 10^{-4} . The following conclusions can be drawn from these numerical results: FQPSK-B delivers the narrowest bandwidth (highest throughput) with reasonable end-to-end loss compared with BPSK/NRZ while GMSK comes in a close second in terms of bandwidth efficiency.¹ At the other extreme, turbo-coded rate 1/3 BPSK/NRZ is the clear choice for achieving power efficiency at the expense of bandwidth that meets the requirements for deep-space applications. Trellis-coded 8-PSK with or without filtering is also an excellent choice for bandwidth efficient operations. Finally, combining the CCSDS-recommended error-correction coding with PCM/PM/NRZ and with BPSK/NRZ are reasonable choices when both power and bandwidth are considerations.

References

- [1] W. L. Martin, T-Y. Yan, and L. V. Lam, "CCSDS-SFCG: Efficient modulation methods study at NASA/JPL, Phase 3: End-to end performance," *Proceedings of the SFGC Meeting*, Galveston, Texas, September 16–25, 1997.
- [2] W. L. Martin and T-Y. Nguyen, "CCSDS-SFCG: Efficient modulation methods study at NASA/JPL, Phase 1: Bandwidth Utilization," *Proceedings of the SFGC Meeting*, Ottawa, Canada, October 13–21, 1993.
- [3] W. L. Martin and T-Y. Nguyen, "CCSDS-SFCG: Efficient modulation methods study at NASA/JPL, Phase 2: Spectrum Shaping," *Proceedings of the SFGC Meeting*, Rothenburg, Germany, September 14–23, 1994.

¹ The demodulator used for GMSK was that based on the AMP representation as discussed in Sec. 2.8.2.6, i.e., a matched filter followed by a Wiener filter.

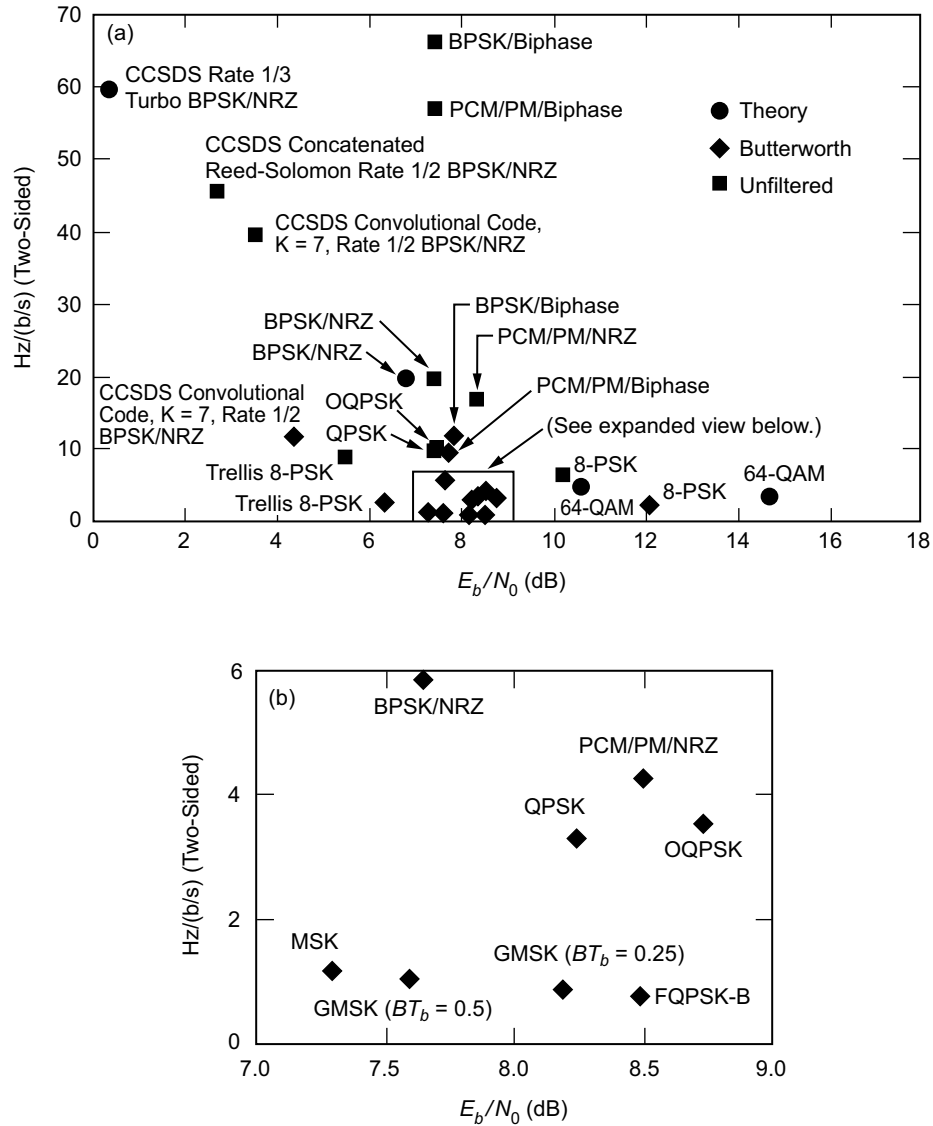


Fig. 6-1. The power-bandwidth trade-off at bit-error probability = 10^{-3} . Power = 99 percent and $BT_s = 2$, unless otherwise specified: (a) full view and (b) expanded view of the box in (a).

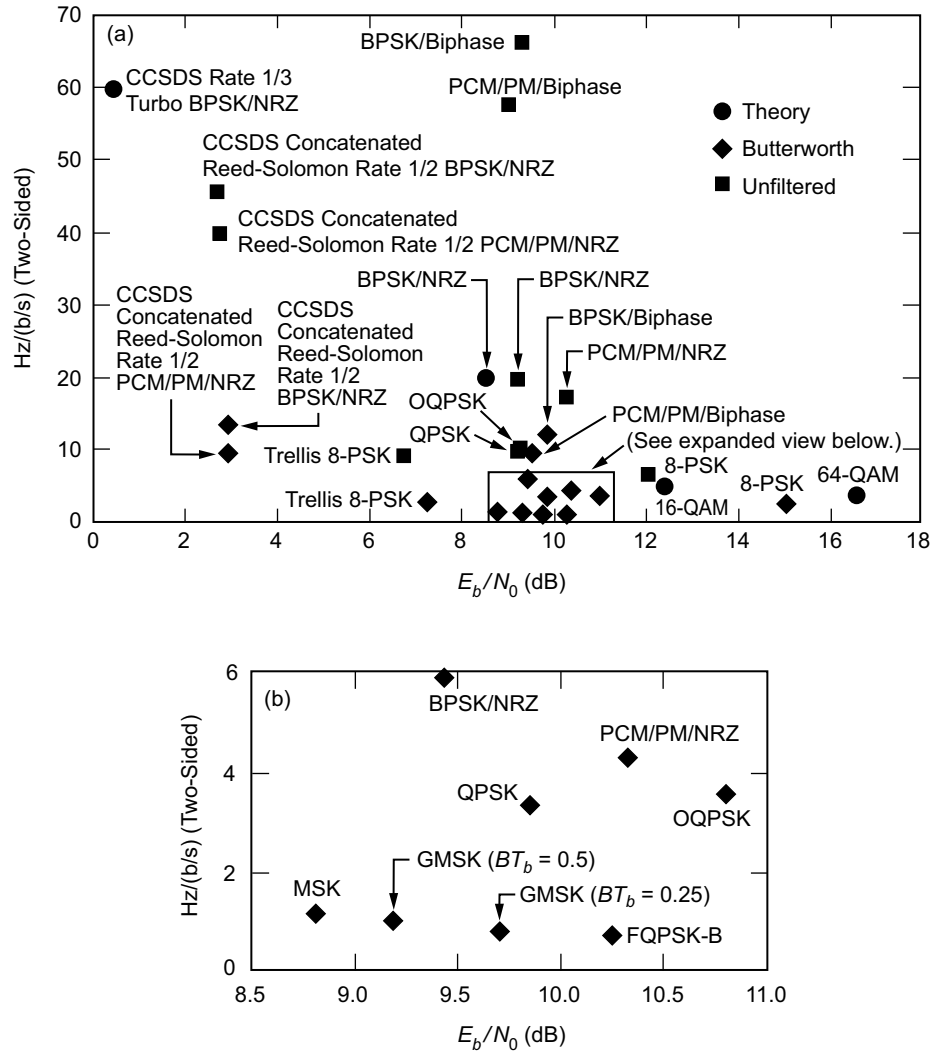


Fig. 6-2. The power-bandwidth trade-off at bit-error probability = 10^{-4} . Power = 99 percent and $BT_s = 2$, unless otherwise specified: (a) full view and (b) expanded view of the box in (a).